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Development and examination of a relay system for automatic control of emission frequency for submerged hydrodynamic generators

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Abstract

A relay system for automatic control of emission frequency for a submerged hydrodynamic generator has been developed and examined. This system provides hydromechanical equipment operation calibration for formation dominant frequency. Mathematical model incorporates the presence of a long hydraulic line in a form of an extended well through which an actuating signal passes. Analytical expressions for amplitude and frequency of auto oscillation occurring in the system are obtained. The increase in delay time in the hydraulic line is found out to result in the decrease of frequency and increase of auto oscillation amplitude that is undesirable for efficient realization of vibroseismic impact. Numerical simulation of control system operation has demonstrated the qualitative validity of obtained theoretical findings.

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Keywords: enhanced oil recovery; vibroseismic impact; well generator; hydrodynamic oscillator; relay control principle; emission frequency

1. Introduction

Presently various types of submerged downhole hydraulic oscillators that are mounted at a bedding depth are used for vibroseismic impact on the oil-producing formation [1-3]. This equipment operation is aimed at creating pressure fluctuation and liquid flow rate within annular space. The fluctuation contributes to micro-fissure network development in the formation porous medium resulting in the increase and recovery of oil production rate.

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Despite sufficient reliability and possibility of necessary emission power production, the employment outlook for this type of oscillators for vibroseismic impact on an oil-producing formation is limited. It is due to the equipment stable operation being in a narrow frequency band and its direct connection to the delivery pump flowrate. Any type of geo-technical massive is known to have its own dominant frequency [4]. In watered oil formations its value lies in 6-18 Hz band and depends on the formation porosity and permeability, borehole fluid viscosity and its coercibility in porous medium.

It is evident that one can select pressure low frequency oscillations mode for the hydrodynamic oscillator resulting in the formation resonance activation. Moreover in terms of vibroseismic impact efficiency, the frequency deviation of generated oscillations from the formation dominant frequency should be minimal.

Taking into account the abovementioned, the aim of developing the system for automatic control of emission frequency for a submerged hydrodynamic generator allowing the operation mode in accord with the formation dominant frequency is of relevance.

2. Study subject

In terms of design, a submerged hydrodynamic oscillator is a solid hydraulic device. Its emission frequency depends on the fluid pressure at the equipment inlet (i.e. the frequency depends on the pump delivery at the well mouth). Considering the delivery pump as a controlled object, one can say [5] that control action would be a change in pump flowrate in relation to discrepancy of actual and intended emission frequencies.

Assuming that the pump with flow-rate controller is mounted at the well mouth, the functional diagram of the system of emission frequency control for a submerged generator would be as shown at Fig. 1.

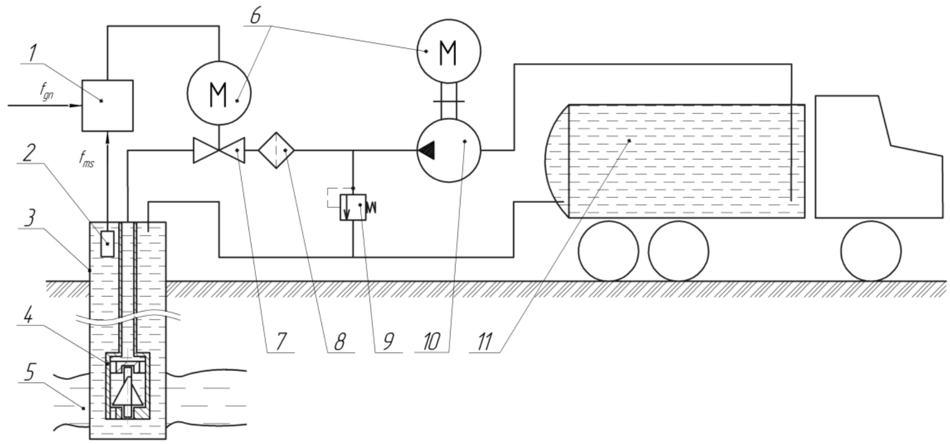

Fig. 1. Functional diagram of emission frequency control: *1* – control system; *2* – pressure sensor; *3* – producing string; 4 – submerged oscillator; *5* – oil producing formation; *6* – electric motor; *7* – flow-rate controller; *8* –filter; *9* – safety valve; *10* – pump; *11* – tank; f_{gn} – intended frequency; f_{ms} – measured frequency.

Taking into account the implementation simplicity (compared to continuous proportional operation systems), a relay control principle is suggested for control system high reliability and operation speed. The ability to operate in an auto-oscillation mode is the key feature of automatic control relay systems.

In the proposed diagram the discrepancy in the controlled value (the discrepancy in intended and measured emission frequencies of generator) is converted into an electrical signal by the control system and transmitted to the relay unit. Should the discrepancy value surpass the relay operating value, a signal appears at the relay outlet and it grows and switches on the flow-rate controller. As soon as the discrepancy in intended and measured emission frequencies becomes acceptable, the relay turns off the flow-rate controller. The electrical relay system accounts for a change in the electric signal sign that corresponds to the change in the direction of the current arriving at the flow-rate controller. Consequently the control system provides an auto-oscillation mode based on the flowrate.

In modeling of the control system, the allowance was made for the presence of holdback in two long hydraulic lines: for transmitting a change in the hydraulic fluid consumption along the producing strings from the well mouth to the downhole part and for transmitting pressure oscillation from the downhole part to the well mouth along the casing string.

In analyzing auto-oscillation systems, to determine the value of the system settings accounting for a consistent auto-oscillation process as well as the impact of the settings on auto-oscillation amplitude and frequency is of practical importance.

The precise knowledge of frequency and oscillation amplitude dependence on the system settings is not necessary in a steady auto-oscillation mode. For engineering purposes it is enough to obtain the general recommendations on any parameter change in order to evaluate its impact on auto-oscillation type. That accounted for the use of a harmonic linearization method [6]. A non-linear dynamic element as the relay was substituted with a linear element with a definite gain ratio taking different values for different amplitudes of the input value. In turn the long hydraulic line was considered as a pure delay element.

Having written the equation for the system elements in deviation and having moved to Laplace domain, the transfer functions of the system dynamic elements were obtained. Rotary generation [7] was taken for hydrodynamic generator. The transfer function of the rotary generator was defined by the formula

$$W_G = T_G^2 p^2 + 2\xi T_G p + 1. \tag{1}$$

The system standard equation was obtained

$$T_R T_G p^4 + (T_G^2 + 2\xi T_R T_G)p^3 + (2\xi T_G + T_R)p^2 + p + \frac{4Ku}{\pi A} e^{-\tau p} = 0. \tag{2}$$

Having replaced $p = j\Omega$ and selected real and imaginary parts, the equation for determining amplitude and frequency of a periodic solution was obtained

$$\begin{cases} \dfrac{4Ku}{\pi A}\cos(\tau \cdot \Omega) - \Omega^4 T_R T_G{}^2 - \Omega^2(2\xi T_G + T_R) = 0, \\ \dfrac{4Ku}{\pi A}\sin(\tau \cdot \Omega) + \Omega^3(T_G{}^2 + 2\xi T_R T_G) - \Omega = 0. \end{cases} \tag{3}$$

To find the system solutions (3) in an analytic form, the multiplication of the time delay value τ and the expected frequency Ω was supposed to be not too large. It allowed for $\tan(\tau \cdot \Omega) \approx \tau \cdot \Omega$. Considering the frequency as positive, the formula for determining auto-oscillation frequency under small values $\tau \cdot \Omega$ was obtained:

$$\Omega \approx \sqrt{\frac{\tau \cdot B_2 + \sqrt{\tau^2 \cdot (B_2)^2 + 2\tau B_2 B_3 - 4\tau B_4 + (B_3)^2} + B_3}{2\tau \cdot B_4}}. \tag{4}$$

The following is the formula for estimating the amplitude of a periodic solution:

$$A \approx \frac{16 \cdot K \cdot u}{\pi\sqrt{\dfrac{B_5}{\tau \cdot B_4}} \cdot \sqrt{\dfrac{8\tau^3 \cdot B_4{}^2 - 4\tau^2 \cdot B_4 B_5(2B_3 - B_2{}^2) + 2\tau B_5{}^2(B_3{}^2 - 2B_2 B_4) + B_4 B_5{}^2}{\tau^3 \cdot B_4{}^2}}}. \tag{5}$$

Due to the formulas (4) and (5), approximation for $\Omega = \Omega(\tau)$ and $A = A(\tau)$ with $T_R = 0.1$ c, $T_G = 0.01$ c, $\xi = 0.5$, $u = 1$ B, $K = 0.5$ is shown in Fig. 2.

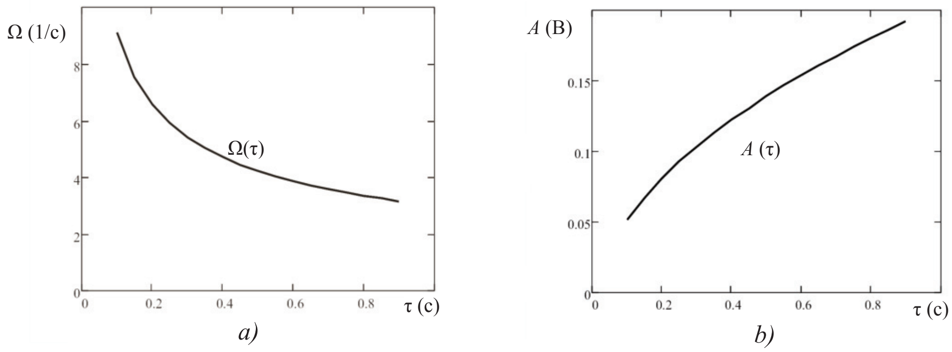

Fig. 2. The graph of approximations for dependence of auto-oscillation frequency (a) and amplitude (b) on the time delay value.

3. Methods

The numerical simulation of the emission frequency automatic stabilization system operation of the hydro impulse generator with a relay control principle was carried out in the extension *Simulink* of software application *Matlab*.

The type of the system auto-oscillation is influenced by the system electromechanic parameters, as well as the time delay of the signal passing along the hydraulic line. With $T_R = 0.1$ c, $T_G = 0.01$ c, $\xi = 0.5$, $u = 1$ B, while changing the value of the system transmission ratio *K*, the auto-oscillation parameters were determined for various time delay values (Fig. 3). Impact assessment for combined ratio of transfer and time constant of intensifying transducer elements on the control system rigidity was undertaken in [8].

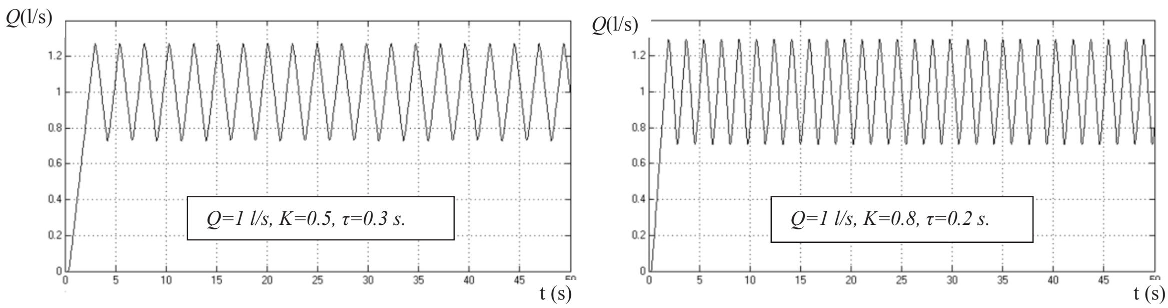

Fig. 3. The graphs for variations of the flowrate *Q* of *the* working fluid, arriving at the hydroimpulse generator for various values of specified flowrate, combined ratio of transfer and time delay value.

4. Results and discussion

The analysis of the curves due to analytic formula for estimated amplitude and frequency of auto-oscillation arising in the system demonstrated that the increase in the time delay in the hydraulic line results in the decrease of the frequency and the increase of auto-oscillation amplitude. It is undesirable for efficient realization of vibroseismic impact.

The numerical simulation of the automatic stabilization system operation demonstrated that stable auto-oscillation respective to the specified flowrate value appears on the completion of a transient process. Moreover the increase in combined transfer ratio results in the increase of auto-oscillation frequency, that stabilizes the mean value of the hydroimpulse generator emission frequency, and, in turn, has a positive effect on the system operation precision.

5. Conclusion

As a result of the conducted research, the relay system for automatic control of emission frequency for a submerged hydrodynamic generator has been developed. The system provides the equipment operation calibration for the formation dominant frequency. Analytical expressions for estimating amplitude and frequency of auto oscillation occurring in the system are obtained.

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